

IoT-Based Regenerative Braking System

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Abstract— Regenerative braking is an advanced energy recovery technique that converts kinetic energy into electrical energy during braking. In conventional systems, this energy is dissipated as heat, leading to significant energy loss and reduced efficiency. This paper presents the design and implementation of an Internet of Things (IoT)-based regenerative braking system using an ESP32 microcontroller. A Permanent Magnet DC (PMDC) motor is used to simulate regenerative braking by operating in generator mode during deceleration. The generated electrical energy is rectified using a diode-based rectifier circuit, filtered using a capacitor, and scaled down using a voltage divider for safe measurement. The ESP32 reads the processed voltage and environmental data from an LDR sensor, and transmits the data to an IoT platform via WiFi for real-time monitoring. The proposed system demonstrates a low-cost, efficient, and scalable approach for energy recovery and smart monitoring applications

Keywords— Regenerative braking, ESP32, IoT, LDR sensor, Blynk

I. INTRODUCTION

The increasing demand for energy-efficient systems has led to the development of technologies that minimize energy loss and improve overall system performance. Regenerative braking is one such technique widely used in electric vehicles and industrial systems. It enables the recovery of kinetic energy during braking and converts it into electrical energy. In conventional braking systems, kinetic energy is wasted in the form of heat due to friction between mechanical components. This results in reduced efficiency and increased wear and tear. [1] Regenerative braking addresses these issues by converting mechanical energy into electrical energy, which can be reused or monitored. The integration of IoT technology further enhances the system by enabling real-time monitoring and data analysis. The ESP32 microcontroller, with built-in WiFi capability, is an ideal platform for implementing such systems. [2] This paper presents an IoT-based regenerative braking system using ESP32, which not only

recovers energy but also provides real-time monitoring through an IoT platform.

II. LITERATURE REVIEW

Various studies have explored the concept of regenerative braking and its applications. Research shows that regenerative braking significantly improves energy efficiency and reduces energy loss in transportation systems. [2] It is widely implemented in electric and hybrid vehicles to enhance performance. Recent advancements focus on integrating IoT technology with regenerative braking systems. IoT-based systems enable remote monitoring, data logging, and performance analysis. The use of microcontrollers such as ESP32 allows efficient data acquisition and wireless communication. Previous research highlights the importance of combining energy recovery with smart monitoring systems to achieve improved efficiency and control.

III. PROBLEM STATEMENT

Conventional braking systems are widely used in vehicles and industrial applications; however, they suffer from several significant limitations that reduce overall system efficiency and performance. One of the major issues is the loss of kinetic energy during braking, which is dissipated as heat due to friction between braking components. This not only leads to energy wastage but also causes overheating, which can reduce braking efficiency and affect system reliability. Additionally, continuous friction results in mechanical wear and tear of components such as brake pads and discs, increasing maintenance costs and reducing the lifespan of the system. [3] Another important limitation of traditional braking systems is the absence of real-time monitoring and data analysis. These systems do not provide any mechanism to measure or track performance parameters such as energy loss, braking efficiency, or system condition. [4] As a result, it becomes difficult to optimize performance or detect faults in advance. These challenges highlight the need for an advanced braking system that can recover lost energy, reduce mechanical stress, and provide intelligent monitoring through modern technologies such as IoT.

IV. PROPOSED SYSTEM

The proposed system consists of a PMDC motor, rectifier circuit, capacitor, voltage divider, ESP32 microcontroller, and LDR sensor. During braking, the motor operates in generator mode and produces electrical energy. This energy is processed through a rectifier and filtering circuit to obtain a stable DC output. [4] The voltage divider reduces the voltage to a safe level for the ESP32. The ESP32 reads the voltage and LDR sensor data using its ADC and transmits the information to an IoT platform using WiFi. This enables real-time monitoring of system performance.

V. HARDWARE IMPLEMENTATION

The hardware implementation of the proposed IoT-based regenerative braking system consists of several interconnected components that work together to generate, process, and monitor electrical energy during braking. The central component of the system is the ESP32 microcontroller, [4] which serves as the main processing and communication unit. It is equipped with built-in WiFi capability and an analog-to-digital converter (ADC), allowing it to read analog signals from sensors and transmit data to an IoT platform for real-time monitoring. The ESP32 operates at a low voltage of 3.3V and is capable of handling multiple input signals simultaneously,

making it suitable for this application. A Permanent Magnet Direct Current (PMDC) motor is used in the system to simulate regenerative braking. [5] During normal operation, the motor converts electrical energy into mechanical energy, causing rotation. When braking is applied, the motor continues to rotate due to inertia and operates in generator mode, converting mechanical energy back into electrical energy. The generated voltage is typically fluctuating or alternating in nature, which cannot be directly used for measurement or processing. To convert the generated voltage into a usable form, a rectifier circuit is employed using 1N4007 diodes. This circuit allows current to flow in only one direction, thereby converting the fluctuating or alternating voltage into pulsating direct current (DC). The rectified output still contains ripples, which are undesirable for accurate measurement. Therefore, a capacitor with a high capacitance value, typically 4700 μ F, is used to smooth the voltage and reduce fluctuations, resulting in a more stable DC output. Since the generated voltage may exceed the safe input range of the ESP32, a voltage divider circuit is used to scale down the voltage to a suitable level. This circuit consists of two resistors, commonly 10k Ω and 22k Ω , connected in series. The output voltage is taken from the junction of the resistors and fed into the analog input pin of the ESP32. This ensures safe operation and accurate voltage measurement. In addition to voltage sensing, an LDR (Light Dependent Resistor) sensor is incorporated into the system to measure ambient light intensity. The LDR is connected in a voltage divider configuration, where its resistance varies with light intensity, producing a corresponding voltage change. This voltage is read by the ESP32 through another analog input pin. The inclusion of the LDR sensor enhances the system by enabling environmental monitoring along with energy measurement. Overall, the hardware components are carefully integrated to ensure efficient energy conversion, accurate sensing, and reliable communication. The combination of regenerative braking and IoT technology results in a smart and efficient system capable of real-time monitoring and analysis.

VI. SOFTWARE IMPLEMENTATION

The software implementation of the proposed IoT-based regenerative braking system is carried out using the Arduino Integrated Development Environment (IDE), which provides a simple and efficient platform for programming the ESP32 microcontroller. The software is responsible for controlling system operations, acquiring sensor data, [5] processing the information, and transmitting it to an IoT platform for real-time monitoring. The ESP32 is programmed using Embedded C/C++

language, and the code is structured to perform continuous data acquisition and communication tasks. At the initial stage, the program begins with the configuration of input pins and initialization of serial communication for debugging purposes. The analog input pins of the ESP32 are assigned for voltage measurement from the regenerative braking circuit and for reading the output of the LDR sensor. The built-in Analog-to-Digital Converter (ADC) of the ESP32 is utilized to convert these analog signals into digital values. Since the ADC has a 12-bit resolution, it provides a range of values from 0 to 4095, allowing accurate measurement of input signals within the 0 to 3.3V range. The software also includes routines for establishing a WiFi connection. The ESP32 connects to a wireless network using predefined credentials such as SSID and password. Once the connection is established, the system is capable of transmitting data to an IoT platform such as Blynk or ThingSpeak. The data transmission is typically carried out using standard communication protocols, enabling reliable and real-time data transfer. During operation, the ESP32 continuously reads the analog values from the voltage divider circuit and the LDR sensor. [6] These raw ADC values are then processed using mathematical calculations to obtain meaningful parameters such as actual voltage and relative light intensity. The processed data is displayed on the serial monitor for local observation and is also transmitted to the IoT platform for remote monitoring. This continuous loop of data acquisition, processing, and transmission ensures that the system provides up-to-date information at all times. The software is designed to be efficient and responsive, ensuring minimal delay in data processing and communication. It also includes basic error-handling mechanisms, such as checking the WiFi connection status and attempting reconnection if the connection is lost. [7] This enhances the reliability of the system and ensures uninterrupted operation. Overall, the software implementation plays a critical role in integrating the hardware components with IoT technology. It enables real-time monitoring, efficient data handling, and remote accessibility, making the system intelligent and user-friendly.

VII. RESULT

The system successfully demonstrates energy generation during braking and real-time monitoring. The output voltage increases with motor speed, confirming the effectiveness of regenerative braking. The IoT platform displays real-time data, enabling remote monitoring and analysis. The integration of LDR sensor provides additional environmental data.

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